A Design of Coreless Permanent Magnet Axial Flux Generator for Low Speed Wind Turbine

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Abstract* – Most of the available generators in the market are a high speed induction generator which requires high rotational speed and electricity to generate a magnetic field. However, there are very few low-speed generators that exist in the market that available for small energy resources. This paper aims to design and simulate a Coreless Permanent Magnet Axial Flux Generator (PMAFG) for low speed wind turbine. An axial flux generator was designed to have a low speed rotation using a permanent magnet of the type Neodymium Iron Boron (NdFeB). The model was examined with excel to data analyzed. Coreless PMAFG is a generator that is enabled to turn on energy at low speeds. The chosen model was Double Rotor – Single Stator (12 Slots 8 Poles) using Infolytica Magnet software. Finite Element Method (FEM) was employed to analyze the phenomena of the magnetic flux. The test was simulated using static rotation method, which rotated every 3 degrees at 350 rpm with 100 turns and 10, 30, 50, 80 and 100 Ohm of load variations. Compare to the calculation of the design, results of the simulation in terms of voltage, current, power and efficiency had been met with only very small errors.

***Keywords* – low speed generator, double rotor – single stator, NdFeB magnet, finite element method, static rotation.**

I. INTRODUCTION

Wind power plant is a renewable energy source that has not received enough attention from the government. This departs from the understanding of the people who think that Indonesia does not have an adequate wind speed. Indeed, in general the territory of Indonesia has a relatively small potential because it is located on the equator. Even so, in Indonesia there are still areas that have the potential to be built wind power plants, which is a *nozzle effect* area or narrowing between two islands or mountain slopes between which the mountains are close together, including Java, southern and northern Sulawesi, most of the NTT regions, some of the Maluku Islands and Papua with an average wind speed reaching 6 m/s [1].

Wind power plants have construction that is quite unique and has its own aesthetics compared to other power plants, where the construction of wind turbines has four types of components is blades, generators, controllers and data loggers. In this study, focus on generator design and modeling. The most widely available electric generators on the market are high speed radial flux types, where this generator requires gear box transmission to get high speed and also needs the help of supplying the initial electrical energy or exicitation voltage to bring up the magnetic field. In addition, most or more than 90% of wind turbines in the world use slip-ring generators that have disadvantages, including: additional costs for slip rings and brush maintenance [2].

Research conducted by Margana for charging 12 volt accumulators, where the generator rotates at a speed of 375 rpm produces a current of 0.11 ampere and a voltage of 11.45 volt. Meanwhile, in the research of Arif Nurhadi, ST, regarding permanent magnet generators 3-phase axial flux that use *Fe* type permanent magnets rotating at speeds of 100 to 700 rpm produced an AC voltage of 2.7 volts to 33.33 volts. The faster of rotor rotates, the greater the voltage generated [3].

As an alternative solution for that problems, we chose a generator that was easy to make and could be applied at low speeds is the flux axial generator. This flux axial generator use a neodymium iron boron NdFeB type permanent magnet that a rotates at low speed. Flux axial generators are a type of synchronous generator other than the radial flux cylinder type. This generator has a compact construction, disk-shaped and large power density, making it possible to rotate constantly and be able to produce high enough output values at low speed. Based on the simulation of the permanent magnet generator axial flux 12S8P, the generator rotates at a speed of 350 rpm, produces a voltage of 12.8 volts and a current of 45 ampere after being given a load of 10-100 Ohm, by speeds every 3 degrees as far as 120 degrees rounds.

The use of a permanent magnet on this flux axial generator, in order to produce a magnetic field in the air gap without requiring an excitation system for external power. In this type of generator the self reinforcement system is used, this generator rotates at a speed of 100-1000 rpm using 12 pairs of coils and 16 pairs of magnets, called the 12S8P axial flux generator. Seeing from the construction that is simple and efficient in use, a permanent magnet generator is one alternative solution for the process of generating electricity [4].

In the process of converting mechanical into electricity energy, a rotor is needed to drive the energy conversion process. In the rotor there is a magnet that has advantages in its use, that is there is no electrical energy absorbed by the magnetic field system so that there is no loss of electrical energy, which means it can increase the efficiency of the generator. In addition, it can produce a greater torque value than using electromagnets. Another advantage is that it has a greater magnetic flux density than using a non-permanent magnet, and further simplifies construction and maintenance.

II. RESEARCH METHOD

An analytical design method will be describe in this section. The permanent magnet type used in this project is Neodymium Iron Boron (NdFeB). The design aimed to determine an initial rotor and stator, coil model and air gap model. In this study the generator designed based on Finite Element Method (FEM) with Infolytica MagNet software. First step to get rename and determine the material used in the generator is initialization and geometry design. It also provide thickness measurement in each part. By these thread, the model can be simulated as well, it covers an important generator components. They are consists of geometry design of stator, rotor, coil, magnet also the both of air gap in rotor and stator [5]. The initialized geometry design of coreless generator permanent magnet of axial flux can be see in figure 1.

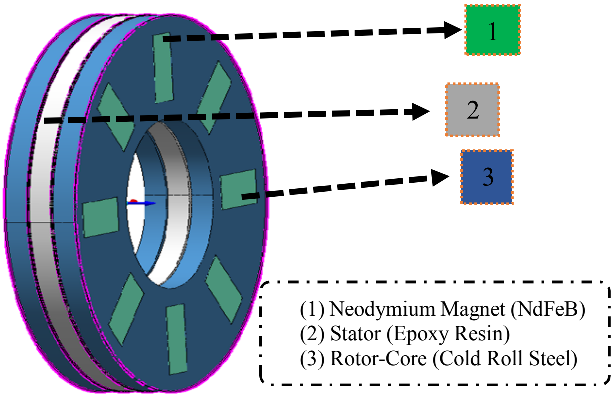

Figure 1. Stator and Rotor Geometry Design GPMAF with MagNet Infolytica Software

We have seen that a torque is generated when a current flows into the motor. In order to understand the relationship between the motor terminal voltage and the current and hereby how there rotational speed is determined, we have to know how electrical power is generated inside the motor, as well as fleming right-hand rule and the back-emf constant.

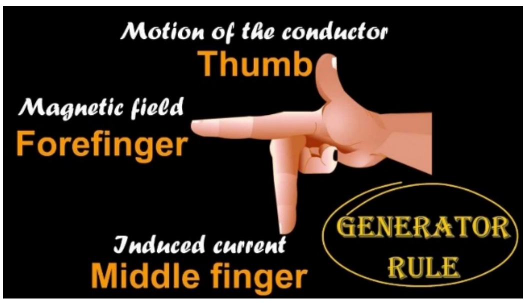

Figure 2. Fleming Right-Hand Rule

As illustrated in figure 2 have the fundamental rules of coreless PMAFG a force works on the conductor, and moves it a speed φ to the left. The conductor is moved by the action of the magnetic field and the current. Since the conductor now passes trough the magnetic field a electromotive force E is generated in the conductor. The magnitude of the force is :

$$E = v\,B\,L \qquad (1)$$

The directions is determined by fleming's right-hand rule. Those are the directions in which the electrical power is generated opposite to the direction of the current, so as to oppose it's flow [6].

After to know of fundamental rules it, the coreles PMAFG have a main dimension of a double rotor-singlestator 12 Slots-8 Poles can be deterimined using the following assumptions :

a) Determined the assumptions of outer and inner diameter PMAFG.
b) Number of slots-poles, voltage, frequency and speed generator.
c) The generator load are known.
d) The number of turns per phase per one stator is N1
e) The phase stator current in one stator winding is show Ia.
f) The back-EMF (Electromotive Forces) for per-phase and per-one stator windings is show Ef.

Rules of breakdown for step that above gived through to determined assumptions of outer and inner generator, where *Dout* is the outer diameter, *Din* is the inner diameter of the stator core and *Kd = Din / Dout*, if look for *Kd* is :

$$\text{Kd} = \frac{Rin}{Rout} = \frac{Din}{Dout} \qquad (2)$$

After to knowed of the diameter geometry coreless PMAFG, now to discover main important subject of it, which is the number of slots-poles, voltage, frequency and speed of generator, where are the number of poles is 2p = 16 pairs and asuming kd = Din / Dout = 1/√3, and the parameter Kd available for those previous explanation:

$$kD = \frac{1}{16} \times \left(1 + \frac{1}{\sqrt{3}}\right) \left(1 + \frac{1}{\sqrt{3}}\right)^2 \qquad (3)$$

The phase current of serries connected non-overlaping stator windings is:

$$Ia = \frac{\text{Pout}}{\text{m1(2V1)}\,\eta \cos\phi} \qquad (4)$$

In additions, the number of stator turns per phase and per slots stator are calculated on the basis of line current density with according to eqn below:

$$N1 = \frac{\pi Dout(1+Kd)Am}{4m1\sqrt{2}Ia} \qquad (5)$$

Meanwhile, after found the variable related for below should determind value of back-EMF (Electromotive Force) to have generated other variable value. The EMF induced in the stator winding by the rotor excitation system, for according to eqns [7]:

$$\text{Ef} = \sqrt{2}\, nspN1kw1\phi f = \frac{\pi}{4}\sqrt{2}\text{ns N1 Kw1 Bmg } D^2out\,(1 - k^2d) \qquad (6)$$

While the finite element or mesh is set to 3 mm for the following parts, the are middle stator, double side rotor and magnet. Other than an initial mesh for double side rotor and stator air gap are set to 0.25 mm respectively. In this study, Coreless Generator Axial Flux has design with detail specification. Table 1 shows the design variable of it:

Table 1. The Variable Designs of Coreless Generator

Permanent Magnet Axial Flux	
Design Variable	**Initials Value**
Magnetic poles	16 Pairs
Magnetic type	Iron Boron NdFeB
Diameter of generator	220 mm
Copper wire diameter	0.8 mm
Number of turns	100 turns
Rotor materials	CR10: Cold Roll 1010 steel
Stator materials	Epoxy resin
Distance air gap rotor and stator	0.25 mm
Number of stator slotes	12 Slots
Coil materials	Copper: 5.77e7 Siemens

III. RESULT AND ANALYSIS

Figure 3 showed the result of flux linkage GPMAF 12 Slotes 8 Poles based on simulation respectively. Flux linkage is a flux that is connected or flowing from rotor to the stator or reverse it. Flux linkage value is to determine the voltage produce by the generator. While each coil voltage is the voltage generated by each coil, in other words it is the voltage of each phase [8].

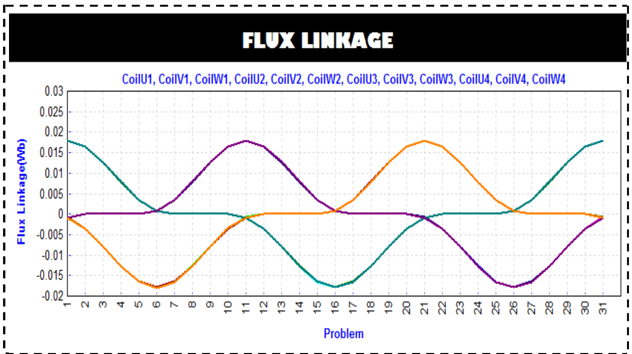

Figure 3. Results Graph of Flux Linkage GPMAF 12 Slotes 8 Poles in Infolytica MagNet Software

The picture below is figure 4 showed the result of voltage line to line relations based on simulation respectively. The voltage has appearces of effect rotations of the rotor to arounded stator. Voltage value is to determine of the flux linkage produce by the rotation rotor. While each coil voltage is the voltage generated by each coil, in other words it is the voltage of each phase. The graph it shows the result of voltage per 3 degrees and average voltage generator permanent magnet axial flux 12 slots 8 poles.

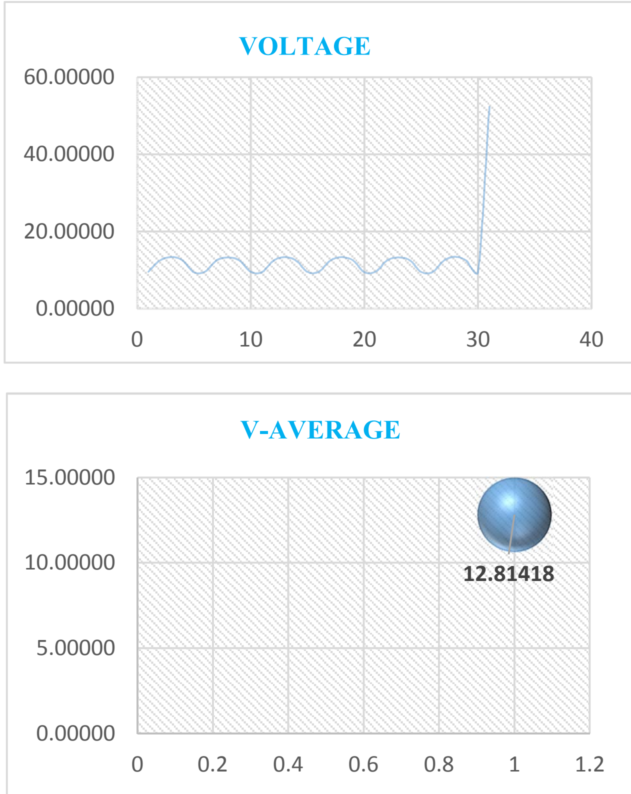

Figure 4. Results Graph of Voltage Line to Line and Point of Voltage-Average Coreless GMPAF 12 Slots 8 Poles

In the figure 5 showed that the output power generated come from the output voltage multiplied by the root of two then divided by the load. The loads assigned to this axial generator is diverse which is (10, 30, 50, 80 and 100 Ω). The power generated at each load, then average so that obtained concrete results on each loaded. It's better understand the results of each output power, it is expressed as percent, where (10 Ω = 57 % ; 30 Ω = 19 % ; 50 Ω = 11 % ; 80 Ω = 7 % ; 100 Ω = 6 %). From the results of those data seen, the smallest load value is 10 Ω to got the greatest power, while the largest load is 100 Ω got the least power. So it can be concluded that, the smallest load of the output power is generated by higher generator, and greatest load gived when the power output by generator is smaller.

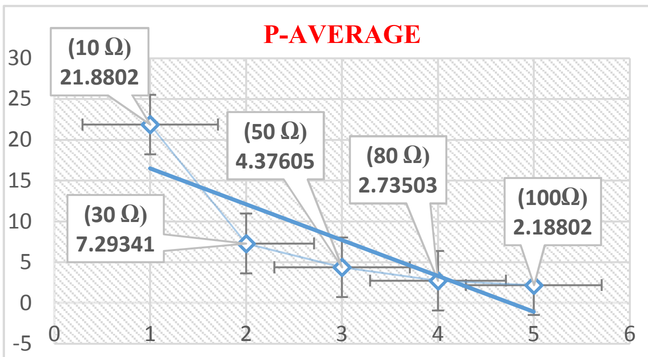

Figure 5. Graph of Output-Power Coreless GMPAF 12 Slots 8 Poles

As for figure 6 below shows that the output current generated come from the output voltage divided by loads. The loads assigned to this axial generator is diverse which is (10, 30, 50, 80 and 100 Ω). The current generated at each load then x average so that obtained concrete results on each loaded. It's better understand the results of each current output, it is expressed as percent where (10 Ω = 57 % ; 30 Ω = 19 % ; 50 Ω = 11 % ; 80 Ω = 7 % ; 100 Ω = 6 %). From the results of those data seen, the smallest current value is 10 Ω to got the greatest current, while the largest current is 100 Ω got the least current. So it can be concluded that the smallest current output is generated by higher of generator, and greatest current gived when the current output by generator is smaller.

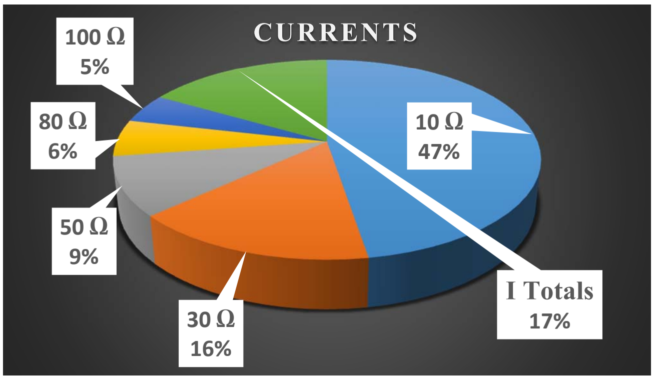

Figure 6. Results Graph of Current-Average with Loads (10, 30, 50, 80 and 100 Ω)

The next picture there is an efficiency which is, the ability of generator to generates electricity, which is obtained from the output power divided by the input power generator. This is an axial generator has various efficiencies obtained in loads variations is (10, 30, 50, 80 and 100 Ω).

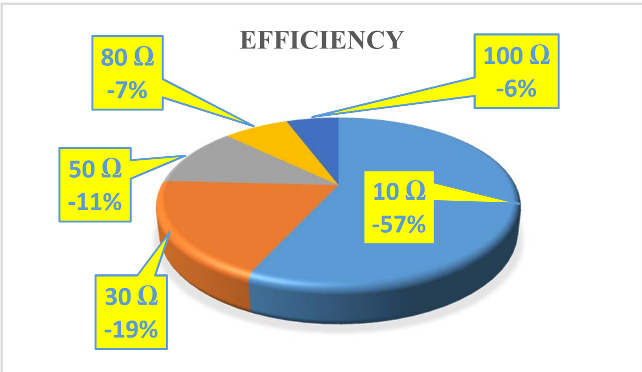

Figure 7. Graph of Efficiencies with Loads Variation (10, 30, 50, 80 and 100 Ohm)

IV. CONCLUSION

An analytical design and simulation is presented in this study. It has been provided a low speed electric coreless PMAFG that suitable for low speed wind turbine application. In term of accuracy of simulation and generator construction, the magnet type of Neodymium Iron Boron (NdFeB) and other variables are mentioned (generator diameter, number of turns, poles of magnet and etc) are considered.

This study is a variation speed of generator for rotation per minutes (Rpm) and much turns of coil also be simulated. Advantages of the desain have been result much more better than previous research wich is, Margana for charging 12 volt accumulators, where the generator rotates at a speed of 375 rpm produces a current of 0.11 ampere and a voltage of 11.45 volt, whole this model of coreless PMAFG had been produces a voltage of 12.8 volts and a current of 45 ampere after being given a load of 10 - 100 Ohm. These got generates result of voltage, current, power and efficiency. When voltage be appearenced got an affect of rotor rotation has toward induction for stator that have it. Furthermore, since power showed those have a loads generator and the last got a current those the division for both of it. Furthermore, the efficiency of coreless PMFAG could be appearanced from divided of power input and output generator.

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